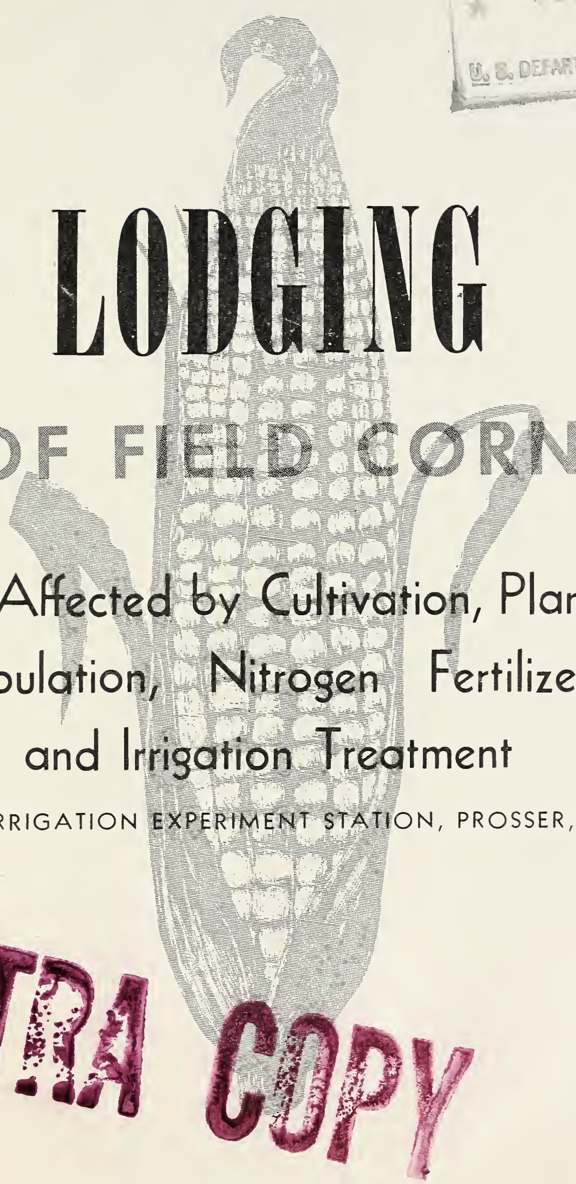

LODGING

OF FIELD CORN

as Affected by Cultivation, Plant Population, Nitrogen Fertilizer, and Irrigation Treatment

AT THE IRRIGATION EXPERIMENT STATION, PROSSER, WASH.

Production Research Report No. 16
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CONTENTS

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LODGING OF FIELD CORN

as affected by cultivation, plant population, nitrogen fertilizer, and irrigation treatment

At the Irrigation Experiment Station, Prosser, Wash.[1]

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INTRODUCTION

Lodging of field corn prior to harvest has become a serious problem in irrigated areas in central Washington since 1945. Lodging has been attributed to spindly stalks caused by greater plant populations per acre. The greater plant populations are the result of better stands from the use of seed treatments, control of soil pests, and higher seeding rates. The use of large quantities of commercial fertilizer also has been named as a contributory cause of lodging. At present, stands of 17,500 plants per acre and applications of fertilizer containing 80 to 250 pounds of available nitrogen per acre are recommended practices for the growers in Washington State (*9*).[2] Crop statistics in the Yakima Valley show yield increases of corn ranging from 20 to 40 percent during the 10-year period, 1946–56.

Growers have reported that their fields often contain 50 to 60 percentage of lodged stalks. Mechanical harvesters cannot recover all the ears from lodged corn plants, thus resulting in a loss of grain to the farmer.

No lodging due to corn borer or lodging caused by stalk or root rots has been reported in irrigated fields of central Washington.

The objectives of the studies on lodging of field corn were: (1) To determine the effects of cultivation, nitrogen fertilization, and plant population on yields and lodging of field corn; (2) to take certain plant measurements and to determine the force required to break the stalks mechanically at a certain stage of growth as a means of evaluating resistance to lodging; and (3) to determine the effects of certain irrigation treatments on lodging.

Objectives 1 and 2 were studied in an experiment in 1955, and objective 3 in an experiment in 1956.

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[1] Cooperative investigations of the Soil and Water Conservation Research Division, Agricultural Research Service, United States Department of Agriculture, and the Washington Agricultural Experiment Stations.

[2] Italic numbers in parentheses refer to Literature Cited, p. 14.

REVIEW OF LITERATURE

The number of corn plants per acre used in various sections of the United States generally ranges from 8,000 to 17,500, depending upon fertility and moisture conditions of the soil. The effect of plant population on yield under certain conditions is well known.

Lodging data are usually obtained (*2, 8, 10, 14*) by counting the number of broken stalks and the stalks leaning more than 45° at the time of harvest, and then calculating the lodging percentage.

Krantz and Chandler (*7*) found that lodging of corn increased with higher plant populations in experiments using 4,000 to 17,500 plants per acre.

Bryan and coworkers (*1*), working with a range of 10,000 to 20,000 plants per acre, concluded there was no advantage in having more than 14,000 plants per acre in regard to yield, and that higher corn populations materially increased lodging.

Long (*8*), working with 8,000 to 16,000 plants per acre, found that lodging became worse with higher plant populations, and that lodging increased with higher nitrogen rates. Krantz and Chandler (*7*) reported that increased nitrogen rates had only a slight tendency to increase lodging.

Koehler, Dungan, and Holbert (*5*) stated that the difference in percentage of leaning plants was not closely associated with yield.

Hall (*2*), in Minnesota, under natural rainfall conditions, reported no relationship existed between lodging and ear height, or stalk cross section, or weight of ear. Hall also used a mechanical device and recorded the force required to pull the stalks over to an angle of 45°, keeping the stalk rigid from the first internode to the point of attachment to the machine by fastening the stalk to a piece of wood. He found a negative correlation between lodging and the force required to pull the stalk to the 45° angle.

Newman and coworkers in Indiana (*10*) indicated that stalk breakage causes more loss of corn and reduction of quality than an equal amount of root lodging. Root lodging occurs if the roots are pulled loose when the ground is soft and generally occurs before the corn is ripe.

Wilson (*15*) reported that plant height was associated with the vigor of a particular strain and was unrelated to lodging. If there were no brace roots, the corn lodged badly. The development of secondary roots was not related to lodging. The length of the three lowest internodes bore a striking relationship to brace-root development and resistance to lodging. In strains of corn resistant to lodging the nodes were closer together. In the field the diameter of the lowest internode had no relation to lodging.

METEOROLOGICAL CONDITIONS

In this arid region, where crops depend almost wholly on irrigation, precipitation is of little importance in corn production. The precipitation was 1.86 inches from May 1 to October 1 in 1955, and 1.47 inches for the same period in 1956.

In 1955 two windstorms, attaining maximum velocities of 51 and 55 m. p. h., occurred on October 7 and November 10. In 1956 one gale, with a maximum velocity of 46 m. p. h., occurred on October 14. The mean wind velocity for October 1955 was 0.43 m. p. h. greater, and in November 1955, 1.81 m. p. h. greater than the wind velocities for the same months in 1956.

EFFECT OF CULTIVATION, PLANT POPULATION, AND NITROGEN FERTILIZER ON LODGING IN 1955

EXPERIMENTAL PROCEDURE

This experiment was conducted on the Roza unit of the Irrigation Experiment Station in Yakima Valley, Wash. The soil was Sagemoor fine sandy loam that had been cropped with corn in 1954.

Wisconsin 641AA hybrid corn (medium maturity) was seeded May 6 in 38-inch rows. The thickly seeded corn was thinned to specific spacings after emergence—9,300, 10,500, 12,900, 17,500, and 26,200 plants per acre—and then sidedressed with ammonium sulfate at the nitrogen rates of 0, 100, 200, and 400 pounds per acre. Treble superphosphate at the rate of 60 pounds P_2O_5 per acre was plowed under during seedbed preparation. The top 8 inches of soil contained about 500 pounds of exchangeable potassium (K) per acre.

The field was irrigated before plowing. Beginning June 29, it was irrigated once every 3 weeks until October 1.

The treatments consisted of 4 cultivation methods—2 depths of cultivation and 2 amounts of hilling the soil; 4 rates of nitrogen application; and 5 within-the-row plant spacings. The main plots consisted of cultivation treatments and rate of nitrogen applications with plant spacing as subplots. The plant-spacing subplots were 6 rows wide and 35 feet long. The experiment was replicated 3 times.

The cultivation methods were:

(1) Deep cultivated with spearhead shovels with diamond points, set 5 inches on each side of the plants, 7 inches deep, and no hilling;

(2) Shallow cultivated 2 inches deep, using knives and duckfeet with no hilling;

(3) Deep cultivated as in (1), then hilled with disks; and

(4) Shallow cultivated as in (2), then hilled with disks. The tillage dates were May 20, May 31, June 17, and June 28.

The following measurements were taken on 10 consecutive plants per plot the last week of September. (1) The standing stalk was mechanically broken by a special device (fig. 1, *A*) that arched the corn within a 3-second time interval and recorded the force to break or to bend the stalk to the ground. Data were recorded on the height above the ground where the break occurred and whether the break was at the node or internode. The lever device (fig. 1, *A*) was 34 inches high at the point of attachment on the stalk. (2) The third internode was cut from the stalk and placed on fulcrums 6 inches apart (fig. 1, *B*), with one of the slightly flattened sides of this internode on top and the other side toward the two fulcrums, and the force required to break the internode mechanically within a 2-second time interval was recorded. (3) The diameter between the two slightly flattened sides at the center of the third internode was measured. (4) Moisture content of the third internode (oven-dry at 70° C.) was determined. (5) Height of plant to the lowermost branch of the tassel and (6) height of the uppermost ear at the point of attachment on the stalk were recorded.

The following measurements were taken at harvest, November 14–23: (1) Lodging, including root lodging and stalk breakage, with

any plant leaning more than 45° recorded as lodged; (2) height of breakage above the ground; (3) ear weight; (4) ears per plant; (5) kernel moisture (oven-dry at 70° C.); and (6) yields in bushels per acre at 15.5 percent moisture.

Statistical procedures and symbols are those given by Snedecor (*13*).

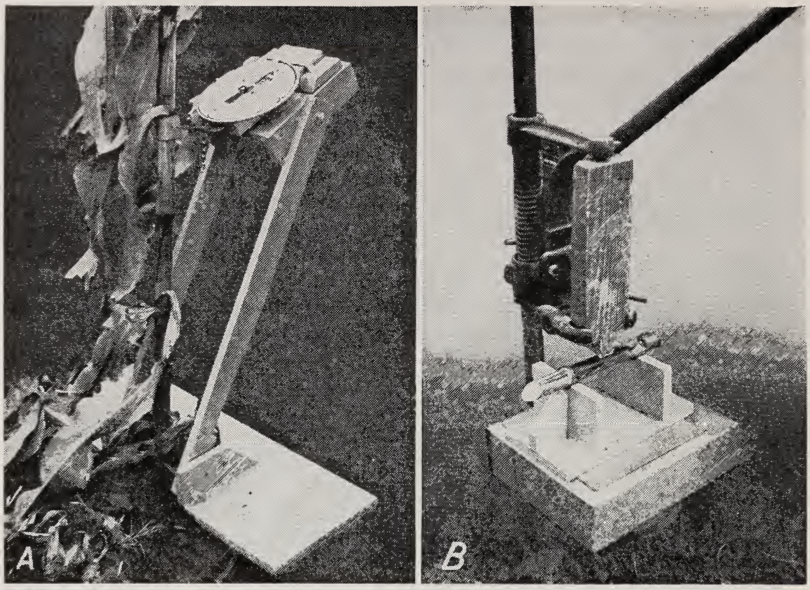

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FIGURE 1.—*A*, Equipment used to break the standing stalks. *B*, A closeup of equipment used to break the third internode. The wooden block shown is placed on the platform of a large-dial scale that indicates the force exerted at the time of breakage.

EXPERIMENTAL RESULTS

The cultivation, spacing, and nitrogen fertility treatments did not affect the moisture in the third internode at the time when the stalk diameter and mechanical breakage measurements were made (appendix, table 8). The average moisture in the third internode was 83.6 percent.

Very few interactions occurred between the plot treatments. Only six first-order interactions and one second-order interaction occurred, all of which were in the measurements of the mechanical breakage of the standing stalk, height of ears, ears per plant, and acre yield. The statistical data are shown in the appendix, table 8.

The height at which mechanical breakage occurred in the standing stalks ranged from 3.15 to 4.83 inches for all treatments, with a coefficient of variation of 71 percent. The breaks occurred at internodes in 72.50 percentage of the stand and at nodes, 11.25. Stalks forced to the ground without breaking accounted for 16.25 percent.

At the time of harvest when lodging counts were taken, the stalk breakage from the treatments receiving no hilling of the soil averaged 11.54 inches, and those from the hilled plots 9.67 inches above the soil. The plant population effects on the height of breakage were: 18.9, 11.3, 9.0, 9.0, and 4.9 inches above the ground for the 9.3, 10.5, 12.9,

17.5, and 26.2 thousand plants per acre, respectively. Nitrogen fertilizer did not affect the height of breakage, and there were no interactions.

CULTIVATION

The cultivation treatments did not affect lodging, but method of cultivation did affect yields and plant vigor (table 1). The shallow cultivation treatment (No. 2) produced less corn and decreased the diameter and breaking force of the third internode, indicating a less vigorous growth of corn from this treatment. The decreased yield resulting from shallow cultivation may possibly be attributed to inadequate nitrification of the ammonium fertilizer and to impediment of water infiltration resulting from soil compaction.

TABLE 1.—*Effects of cultivation on measurements related to lodging of corn, Prosser, Wash., 1955*

Treatment: No.	Treatment: Cultivation method	Breaking force: Standing stalk	Breaking force: Third internode	Diameter, third internode	Stalk height	Ear height	Ears per plant	Ear weight	Lodging	Acre yield
		Pounds	*Pounds*	*Inch*	*Inches*	*Inches*	*Number*	*Pound*	*Percent*	*Bushels*
1	Deep cultivated	6.10	116	0.969	100	43.2	1.13	0.73	31.4	132.3
2	Shallow cultivated	5.43	103	.946	100	42.4	1.09	.64	29.1	113.3
3	Deep cultivated and hilled	5.87	113	.961	99	40.6	1.12	.72	25.5	128.0
4	Shallow cultivated and hilled	6.21	113	.977	100	41.4	1.15	.73	30.2	134.3
Least significant difference at 5-percent level		(1)	8.14	.023	(1)	1.32	.03	.05	(1)	9.6
Coefficient of variation (percent)		15.5	13.3	4.3	4.1	3.7	4.1	7.2	29.7	13.3

1 Not significant.

NITROGEN FERTILIZATION

The plants from the 100-pound nitrogen treatment lodged more than the plants from the unfertilized (check) treatment (table 2). This difference was significant at the 1-percent level. Differences in lodging among the 100-, 200-, and 400-pound nitrogen treatments were not significant. Differences also among the 3 rates of nitrogen were not significant for 8 of the 9 other measurements of plants, as shown in table 2. Therefore, the 3 treatments receiving nitrogen will be discussed collectively as nitrogen treatments.

TABLE 2.—*Effects of nitrogen rates on measurements related to lodging of corn, Prosser, Wash., 1955*

Nitrogen rate (pounds per acre)	Breaking force: Standing stalk	Breaking force: Third internode	Diameter, third internode	Stalk height	Ear height	Ear weight	Ears per plant	Kernel moisture at harvest	Lodging	Acre yield
	Pounds	*Pounds*	*Inch*	*Inches*	*Inches*	*Pound*	*Number*	*Percent*	*Percent*	*Bushels*
0	5.05	109	0.914	97	40.5	0.61	1.10	27.1	22.8	108.2
100	6.16	113	.961	101	42.5	.73	1.12	26.5	29.6	132.5
200	6.20	112	.989	100	42.2	.73	1.13	26.8	31.9	133.2
400	6.20	111	.989	101	42 4	.73	1.13	26.2	31.9	134.1
Least significant difference at 5-percent level	.67	(1)	.024	2.0	1.3	.05	(1)	(1)	4.4	9.6
Coefficient of variation (percent)	15.5	13.3	4.3	4.1	3.7	7.2	4.1	9.1	29.7	13.3

1 Not significant.

The measurements taken of the stalks September 26 to 30 show that the force required to break the stalks mechanically and the diameter of the third internode were greater for the nitrogen treatments than for the unfertilized treatment. This did not reduce the lodging, however, because, as shown in table 2, the plants from the nitrogen treatments lodged more than those from the unfertilized treatment. This may be attributed to the stalks drying by the time of harvest and to the greater ear weight and the ear and plant height, which caused the plants to break from impact of fall storms. The nitrogen treatments did not affect the moisture content of the grain at the time of harvest, November 14 to 23.

PLANT POPULATIONS

Diameter of the third internode, as well as the force required to break the standing stalk and the third internode, increased with decreasing plant population (table 3). The stalk and ear height decreased as the number of plants per acre decreased. The number of ears per plant and average ear weight increased as plant population decreased from 26 to 13 thousand plants per acre.

TABLE 3.—*Effects of plant population on measurements related to lodging of corn, Prosser, Wash., 1955*

Plants per acre	Breaking force		Diameter, third internode	Stalk height	Ear height	Ears per plant	Ear weight	Kernel moisture at harvest	Lodging	Acre yield
	Standing stalk	Third internode								
	Pounds	*Pounds*	*Inches*	*Inches*	*Inches*	*Number*	*Pound*	*Percent*	*Percent*	*Bushels*
9,300	8.24	148	1.068	93	37.5	1.29	0.78	26.6	13.9	107.9
10,500	7.53	131	1.036	96	39.2	1.22	.78	26.9	16.7	116.7
12,900	6.39	120	.993	99	41.3	1.11	.78	26.2	22.9	129.5
17,500	4.28	89	.894	104	44.9	1.03	.68	26.1	40.8	141.7
26,200	3.05	68	.820	106	46.7	.94	.49	27.4	61.3	139.2
Least significant difference at 5-percent level	1.17	6.0	.016	1.7	.6	.02	.02	.8	4.4	6.8
Coefficient of variation (percent)	15.5	13.3	4.3	4.1	3.7	4.1	7.2	9.1	29.7	13.3

The moisture in the grain from the stand of 26,000 plants per acre was slightly greater than that from the lesser plant populations.

Figure 2 shows the regression of yields on plant population. Since the yields from the 100-, 200-, and 400-pound nitrogen fertilizer rates were not significantly different, only one regression line is given for the three treatments. The difference in yields (fig. 2) between the nitrogen treatments and the unfertilized treatment increased progressively with the higher plant populations. The maximum yield for either treatment was at about 20,000 plants per acre. Beyond that population the unfertilized treatment yields decreased more rapidly than did those from the fertilized treatments.

The regression of lodging on plant population is shown in figure 3. Lodging increased with plant population. The nitrogen fertilization also increased lodging, and to a much greater extent as the plant population increased. As population increased, the relationship more nearly approached linearity than did that from the unfertilized treatment.

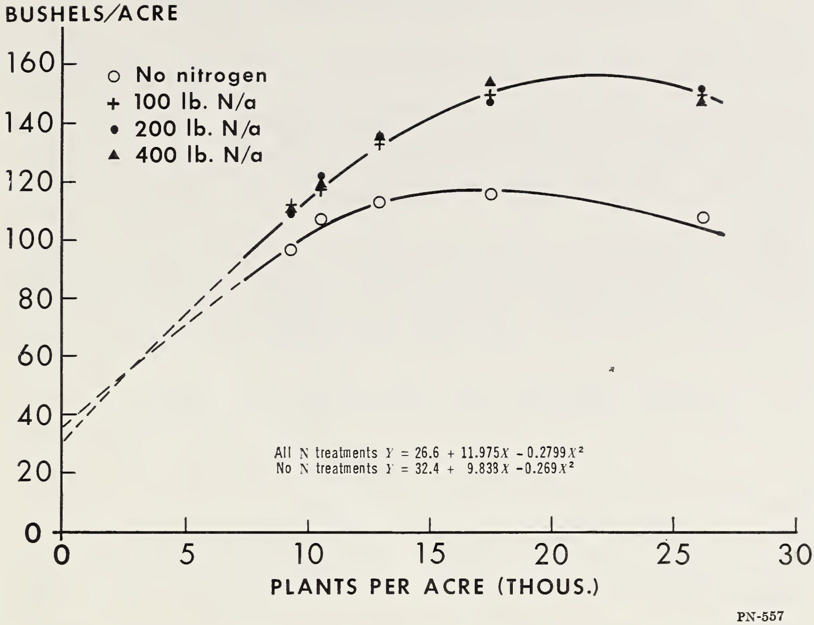

Figure 2.—Regression of yields of corn on plant population, with nitrogen applied at different rates.

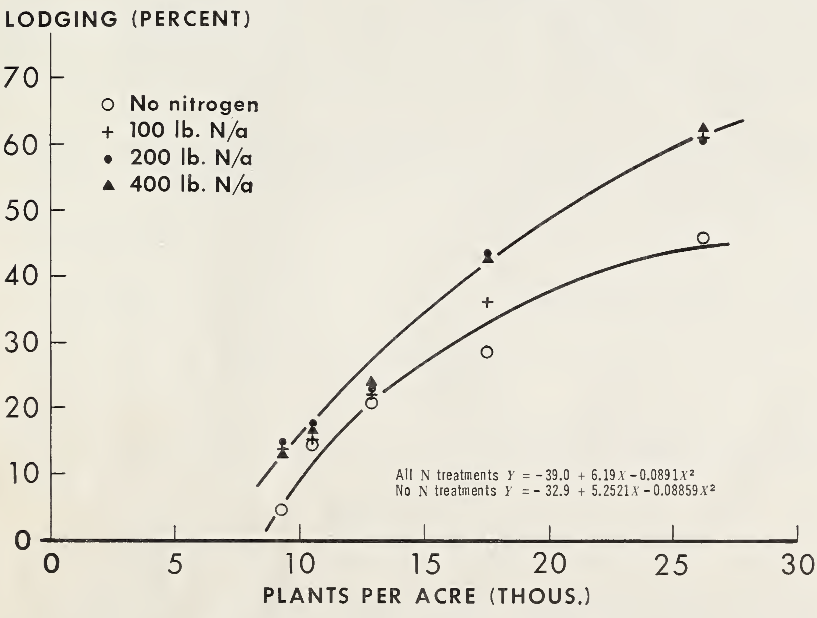

Figure 3.—Regression of stalk lodging on plant population of field corn, with nitrogen applied at different rates.

The simple correlation coefficients and regression equations of lodging on six measurements are shown in table 4. All measurements are correlated with lodging, but diameter of the third internode, force to break the standing stalk and the third internode, and the ear height are most highly correlated with lodging and have the highest predictive value. The correlation of lodging with yield and correlation of lodging with stalk height are considerably less, although highly significant.

The force required to break the third internode had the highest predictive value of the first three measurements in predicting lodging ($r^2=0.58$), and it seemed desirable to determine whether the prediction equation could be improved by multiple regression analysis, including the force required to break the standing stalk (x_1) and the diameter of the third internode (x_2). Table 5 shows that the inclusion of these two additional independent variables has improved the prediction equation, the coefficient of multiple determination being 0.6489. The partial regression coefficients shown in table 5 show that the force required to break the third internode is the independent variable having the greatest effect on lodging.

TABLE 4.—*Simple correlation coefficients and the regression equations of the percentage of lodged corn plants* (*Y*) *on certain measurements* (*x*) *taken, Prosser, Wash., 1955* [1]

Measurement No.	Independent variable	r_{yx}	Regression	S_b
1	Force to break standing stalk .... lb	−0.73**	$Y=61.75-5.54x_1$	0.1064
2	Diameter of third internode .... cm	−.65**	$Y=139.61-45.31x_2$	3.41
3	Force to break third internode .... lb	−.76**	$Y=75.91-0.4218x_3$	.0236
4	Yield per acre .... bu	.42**	$Y=-6.93+0.2833x_4$	.0394
5	Stalk height .... in	.46**	$Y=15.62+0.1347x_5$	.1890
6	Ear height .... in	.76**	$Y=-111.6+3.35x_6$	.1875

[1] **=Significant at 1-percent level; $r=0.17$; $P=0.01$; degrees of freedom=238.

TABLE 5.—*Multiple linear regression statistics, showing effects of certain measurements* (*X*) *on percentage of lodged corn plants* (*Y*), *Prosser, Wash., 1955*

Measurements	Standard partial regression coefficients
X_1 .... Force to break standing stalk	−0.4167 ($b'_{y1.23}$)
X_2 .... Diameter of third internode	0.3573 ($b'_{y2.13}$)
X_3 .... Force to break third internode	−0.7630 ($b'_{y3.12}$)
Equation: $Y=-3.1627_{x_1}+24.57_{x_2}-0.4248_{x_3}+34.36$ $R^2=0.6489$ $R=0.8055$	
X_1 .... Force to break standing stalk	−0.5128 ($b'_{y1.23}$)
X_3 .... Force to break third internode	−0.0369 ($b'_{y2.13}$)
X_6 .... Ear height	0.5681 ($b'_{y3.12}$)
Equation: $Y=-3.8938_{x_1}-0.0205_{x_3}+2.5130_{x_6}-51.25$ $R^2=0.8341$ $R=0.9133$	

Of the three remaining independent variables, the height of ear was the most highly correlated with lodging. When the variable is included with the force to break the standing stalk and the third inter-

node, the partial regression coefficients in table 5 show the ear height and force to break the standing stalk to be nearly equal in predicting lodging, and that the force to break the third internode to be the least important of the three.

A multiple regression analysis was made to include only the force required to break the third internode, the force to break the standing stalk, and lodging. The partial regression coefficient of the force to break the third internode was −0.4801 and the force required to break the standing stalk −0.3622.

If only one measurement were to be taken for predicting the lodging potential, the force required to break the third internode would be the preferred measurement. If two measurements were to be made, the force required to break the standing stalk and the ear height would give the best predictive lodging data.

EFFECT OF IRRIGATION ON LODGING IN 1956

EXPERIMENTAL PROCEDURE

The experiment was conducted on Ritzville fine sandy loam on the Roza unit of the Irrigation Experiment Station, Prosser, Wash. This soil contained adequate amounts of phosphorus and potassium and received 400 pounds nitrogen per acre as ammonium sulfate, which was broadcast and plowed under. Wisconsin 641AA corn was seeded May 2, 1956, in 38-inch rows, and was thinned to 17,500 plants per acre shortly after emergence. Six-row plots 300 feet long were used. The irrigation treatments, replicated 4 times, were:

(1) Normal irrigation up to time of tasseling on July 25; no additional water during season.
(2) Normal irrigation up to time of tasseling, with one subsequent irrigation August 10.
(3) Normal irrigation throughout season, the last of which was applied October 8.

The normal irrigation treatment consisted of irrigating before plowing, again on June 11, and at 20-day intervals thereafter. At no time did the plants wilt between irrigations. The interval between irrigations was based on a corn-irrigation study (*12*) conducted on an adjacent field of the same soil type in 1952.

During the first week in September four 7-foot steel fence posts were placed 16 feet apart in one corn row in each plot. The corn was attached to two wires that were stretched between the posts to prevent natural stalk breakage in plants to be tested for breaking strength.

Beginning September 9, 10 consecutive unsupported stalks were cut at the ground level from each plot. The kernel moisture, diameter of the third internode, internode moisture, and force necessary to break the third internode were determined periodically, as given in table 6.

When stalk breakage from natural causes became evident, the stalks were taken from the row with wire-supported stalks.

The cornstalk sections were cut lengthwise several times to facilitate oven-drying at 70° C.

On November 8 two unsupported rows 30 feet long from each plot were harvested for grain yield. The natural stalk breakage was determined by counting broken stalks and standing plants in the plots.

EXPERIMENTAL RESULTS

The third internodes of corn plants from irrigation treatment No. 1, which received the last irrigation at tasseling, contained less moisture, were broken mechanically with less force, and had more natural breakage than did those from treatment No. 3, which was irrigated all season (table 6).

TABLE 6.—*Effects of irrigation treatments at harvest on the mean stalk breakage characteristics, yields, and grain moisture of Wisconsin 641AA field corn, Prosser, Wash., 1956*

Treatment: No.	Treatment: Irrigation method	Third internode: Diameter	Third internode: Moisture content	Third internode: Breaking force	Lodging	Acre yields	Kernel moisture at harvest
		Inch	*Percent*	*Pounds*	*Percent*	*Bushels*	*Percent*
1	Normal irrigation up to time of tasseling only.	0.827	78.40	86.0	32.5	131.1	16.2
2	Normal irrigation up to time of tasseling with one subsequent irrigation.	.855	83.10	93.4	22.3	150.7	17.2
3	Normal irrigation during season up to October 9.	.855	84.35	106.7	15.1	148.5	17.5
Least significant difference at 5-percent level		(1)	3.80	10.5	[2] 14.0	15.5	(1)
Coefficient of variation (percent)		5.39	6.54	17.0	34.8	6.2	8.8

[1] Not significant.
[2] $P=0.07$.

One extra irrigation after tasseling (treatment 2) increased the stalk moisture, and although the third internode strength was significantly less than in the full irrigation treatment, the difference in the natural stalk breakage was not significant.

The data in table 6 show no differences in the diameter of the third internode or in moisture content of the grain at harvest. Irrigation treatment 1 produced less grain than did the other two treatments.

The effects of time of sampling on the kernel moisture, moisture in the third internode, and the force required to break the third internode are given in table 7. All three measurement values decreased with time. The force required to break the third internode was correlated with the third-internode moisture content ($r=0.61^{**}$). Regression analysis shows that the relationship is curvilinear: $Y=337.57-10.73X+0.09419X^2$, where Y is the force to break the third internode and X is the moisture content of the third internode.

TABLE 7.—*Average effect of time of sampling on the moisture content and the breaking force of the third internode and the grain moisture of Wisconsin 641AA corn, Prosser, Wash., 1956*

Sampling date	Third internode: Moisture content	Third internode: Breaking force	Kernel moisture
	Percent	*Pounds*	*Percent*
September 5	87.00	126.4	48.1
September 19	84.75	111.5	31.4
October 4	83.42	92.1	24.1
October 19	78.00	83.6	15.2
November 5	76.00	63.3	17.0
Least significant difference at 5-percent level	4.89	13.4	1.97
Coefficient of variation (percent)	6.54	17.0	8.82

Effects of time of sampling and irrigation treatments on the stalk moisture are apparent in four sections of the stalks (fig. 4). The rapidity of drying of the stalk below the sixth and seventh internodes is of most importance, as internodes three to five are below the uppermost ear, which exerts a weight-leverage effect when moved by the wind.

Table 7 shows that the grain moisture decreased to 15.2 percent on October 19, after which grain moisture did not decrease.

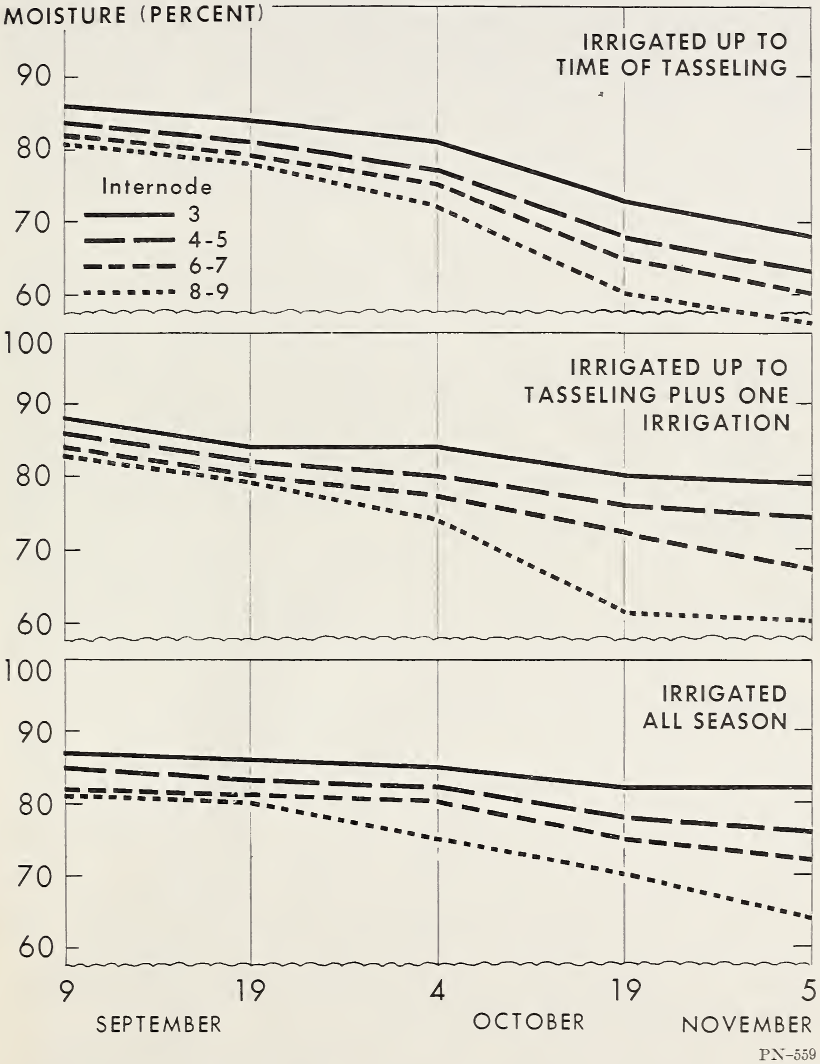

FIGURE 4.—Effects of irrigation treatments and time of sampling on moisture content of certain cornstalk sections.

DISCUSSION

The cultivation treatments did not influence lodging, because root lodging was of minor importance. However, the shallow cultivation treatment, in which only the top 2 inches of soil was disturbed, produced less grain yield than the more deeply cultivated treatments.

General statements (*3*, *11*) are commonly made that shallow cultivation has been superior to deep cultivation. However, the work presented in this bulletin and that of Kiesselback (*4*) show that deep cultivation results in higher corn yields than shallow cultivation. Kiesselback states that normal shovel cultivation 4 to 5 inches deep and not closer than 9 inches to the plant will do little permanent injury under Nebraska conditions. He does state, however, that lodging was increased on close- and late-cultivated treatments. His range of lodging was from 15 to 20 percent. The experiment in Nebraska was under natural rainfall conditions. Under irrigated conditions in the Washington State experiment presented here, it is suggested that perhaps new roots replaced those pruned by the deep and close cultivations, where the last cultivation was done at the time corn was 2.5 feet high.

Nitrogen fertilization resulted in the expected increase in lodging. In spite of the fact that the nitrogen increased the breaking strength of the stalks and diameter of the third internode, this was more than offset by increased ear weight and stalk and ear height. Cornstalk moisture decreases with time after September 1, and resistance to lodging decreases in relation to the stalk moisture. Maintaining the soil moisture late in the fall decreases the amount of lodging.

From the standpoint of yields, it is not practical to reduce the rates of nitrogen fertilization in order to reduce lodging. It would be practical to harvest early in order to take advantage of the greater resistance of the corn to lodge from nitrogen fertilization before the stalks lose a great deal of moisture.

In the irrigated area of central Washington where high rates of nitrogen fertilizer are recommended (*9*) and used, about 20,000 plants per acre should be used in order to obtain maximum production. Precision planting is needed, as small decreases in plant population below that recommended materially decrease the grain yields.

Some workers (*2*) have reported no relationship between ear height, diameter of the third internode, and lodging, and others (*5*, *6*) that yield or nitrogen fertilization had little or no effect on lodging. These experiments, conducted under natural rainfall conditions, had certain limitations of plant populations, plant growth, and yields, due to uncontrollable moisture conditions. The data from the experiment under irrigation reported here show that ear height, diameter of the third internode, and yields were all correlated with lodging.

In the experiments presented, the observed lodging data taken in the conventional manner had coefficients of variability of 29.7 and 34.8 percent, respectively, in 1955 and 1956. This variability can be expected, as lodging depends on the vagaries of the weather and the location of any given plot in the field receiving windbreak protection due to topography or adjoining plants.

The data presented point out that mechanical breaking measurements of the stalk and ear height, which had a coefficient of variability ranging from 3.7 to 17.0 percent, are of considerable value when

lodging data are to be taken along with other agronomic data in studies with field corn.

SUMMARY

The effect of cultivation methods, plant populations, nitrogen fertilization, and irrigation treatments on lodging and yields of Wisconsin 641AA field corn free from root rot and corn borer conditions were studied.

Lodging data were taken in November in the conventional manner by counting broken and lodged stalks in the plots. Mechanical breakage of the standing stalk and the third internode made in September and the measurements of other plant characters were investigated as possible indices of the lodging potential.

Deep, close cultivation or shallow cultivation with or without hilling the soil did not affect lodging. Shallow cultivation without hilling decreased the yields of grain.

Nitrogen fertilization increased lodging. Early in the fall mechanical breakage of the diameter of the measurements of the third internode indicated the stalks from the nitrogen fertilization treatments to be more resistant to breakage. However, in the late fall this was more than overbalanced by increased ear weight and stalk and plant height as the stalk moisture decreased.

Lodging increased progressively with plant populations ranging from 9,300 to 26,200 plants per acre.

The regression of lodging on plant population for the nitrogen-fertilized treatment more closely approached linearity than did that from the nonfertilized treatment.

Grain yields increased as plant populations increased from 9,000 to 20,000 plants per acre. However, the regression on yields on plant population for both the check and nitrogen fertilizer treatment were curvilinear. The yields of the check treatment decreased more rapidly from 20,000 to 26,000 plants per acre than that for the nitrogen-fertilized treatment.

Significant relationships were shown among the mechanical force needed to break the standing stalk or the third internode, the diameter of the third internode, the height of ear, and the yield of grain with lodging.

The best single measurement for determining the lodging potential was the force needed to break the third internode on fulcrums 6 inches apart. In combination, the best two measurements were ear height and the force needed to break the standing stalk. The data presented show that these measurements are of considerable value when lodging data are to be taken in studies with field corn. This is especially true in the absence of lodging due to particularly favorable weather conditions.

In the irrigation experiment the force to break the third internode was highly correlated with stalk moisture content.

Corn irrigated at 20-day intervals throughout the season up to October 9 was less susceptible to lodging than that from two similar treatments which received the last irrigations July 20 or August 10.

The grain moisture content at harvest, November 8, was not affected by irrigation treatments.

Corn from the treatments receiving the last irrigation July 20, August 10, and October 8 yielded 131.1, 150.7, and 148.5 bushels per acre, respectively.

The reduction of stalk moisture was a function of time from September 9 to November 5, which was the time interval studied and when lodging was expected to occur.

It was shown that maintaining adequate soil moisture late in the season and harvesting early as possible are desirable to avoid lodging.

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APPENDIX

Table 8.—*Sums of squares and mean squares from analysis of variance of the corn lodging experiment at Prosser, Wash., in 1955* [1]

Variant	Degrees of freedom	Third internode				Kernel moisture at harvest (percent)	
		Diameter (centimeters)		Moisture content (percent)			
		Sums of squares	Mean squares	Sums of squares	Mean squares	Sums of squares	Mean squares
Replication	2	1.13	0.565	348.07	172.03	43.8	2.19
Cultivation (C)	3	.26	.086*	22.50	7.50	5.4	1.80
Nitrogen rate (N)	3	1.36	.453**	6.50	2.17	25.1	8.37
C X N	9	.15	.016	12.07	1.34	109.3	12.14
Error a	30	.82	.027	113.30	3.78	183.5	6.12
Main plot total	47	3.72		502.54		367.1	
Spacing (S)	4	13.11	3.277**	6.90	1.72	50.9	12.72*
S X C	12	.11	.009	17.57	1.46	98.0	8.17
S X N	12	.19	.016	51.80	4.32	30.1	2.51
S X N X C	36	.44	.012	152.11	4.22	96.9	2.69
Error b	128	1.42	.011	247.49	1.93	498.3	3.89
Total	239	18.99		978.41		1,141.3	

Variant	Degrees of freedom	Stalk height (inches)		Ear height (inches)		Ear weight (not dry at harvest) (pound)		Ears per plant	
		Sums of squares	Mean squares	Sums of squares	Mean squares	Sums of squares	Mean squares	Sums of squares	Mean squares
Replication	2	426	213	275	137	0.84	0.420	0.32	0.1600
Cultivation (C)	3	107	35	225	75**	.36	.120**	.16	.0533**
Nitrogen rate (N)	3	486	162**	165	54**	.62	.306**	.04	.0133
C X N	9	190	21	111	12	.04	.004	.28	.0311**
Error a	30	904	30	375	12	.54	.018	.25	.0083
Main plot total	47	2,113		1,148		2.40		1.05	
Spacing (S)	4	5,693	1,173**	2,853	713**	3.14	.785**	3.77	.9420**
S X C	12	307	26	134	11.2**	.03	.002	.08	.0067**
S X N	12	244	20	83	6.9**	.04	.003	.01	.0004
S X N X C	36	410	11	162	4.5	.20	.006	.13	.0036
Error b	128	2,186	17	309	2.41	.33	.003	.27	.0021
Total	239	10,953		4,689		6.14		5.31	

Variant	Degrees of freedom	Acre yield (bushels)		Breaking force, third internode (pounds)	
		Sums of squares	Mean squares	Sums of squares	Mean squares
Replication	2	45,056.9	22,284.5	32,965	16,482
Cultivation (C)	3	16,160.9	5,387.0**	5,987	1,996*
Nitrogen rate (N)	3	28,401.3	9,467.1**	434	145
C X N	9	5,101.9	566.9	2,511	279
Error a	30	20,039.0	688.0	14,302	477
Main plot total	47	114,760.0		56,199	
Spacing (S)	4	40,497.3	10,124.3**	202,190	50,547**
Linear	1	36,891.9	36,891.9**	197,235	197,235**
Quadratic	1	1,839.8	1,839.8*	2,672	2,672*
S X C	12	3,295.0	274.6	2,366	197
S X N	12	6,339.3	528.3*	3,125	260
S X N X C	36	2,884.6	80.1	4,250	118
Error b	128	36,594.4	285.9	28,007	219
Total	239	204,370.4		296,137	

[1] * = Significant at the 5-percent level; ** = significant at 1-percent level.

TABLE 8.—*Sums of squares and mean squares from analysis of variance of the corn lodging experiment at Prosser, Wash., in 1955* [1]—Continued

Variant	Degrees of freedom	Height of mechanical stalk breakage (inches)		Height of natural stalk breakage in November (inches)	
		Sums of squares	Mean squares	Sums of squares	Mean squares
Replication	2	23	12.50	367	183
Cultivation (C)	3	47	23.50	297	99*
Nitrogen rate (N)	3	25	7.50	8	2
C X N	9	115	12.78	98	11
Error a	30	341	11.37	862	29
Main plot total	47	551		1,632	
Spacing (S)	4	96	24.00*	5,112	1,278.0**
S X C	12	96	8.00	381	32
S X N	12	130	10.83	577	48
S X N X C	36	204	5.67	1,872	52
Error b	128	1,053	8.22	3,357	26
Total	239	2,130		12,931	

Variant	Degrees of freedom	Lodging (percent)		Force to break standing stalk (pounds)	
		Sums of squares	Mean squares	Sums of squares	Mean squares
Replication	2	795.65	397.82	247.6	123.8
Cultivation (C)	3	1,156.45	385.48	21.2	7.1
Nitrogen rate (N)	3	3,368.42	1,122.81**	58.2	19.4**
C X N	9	1,291.54	143.50	16.5	1.8
Error a	30	4,230.35	141.01	95.0	3.2
Main plot total	47	10,842.41		438.5	
Spacing (S)	4	66,961.39	16,740.35**	917.2	229.3**
Linear	1	61,465.34	61,465.34**	891.3	891.3**
Quadratic	1	5,360.16	5,360.16**	13.6	13.6*
S X C	12	1,233.88	102.82	6.9	.6
S X N	12	1,576.32	131.36	23.0	1.9*
S X N X C	36	1,655.37	45.98	98.8	2.7**
Error b	128	9,523.47	74.40	107.9	.8
Total	239	91,792.84		1,592.3	

[1] *=Significant at the 5-percent level; **=significant at 1-percent level.

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